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BULLETIN NO. 19

COMPARATIVE TESTS OF CARBON, METALLIZED CARBON AND TANTALUM FILAMENT LAMPS

BY

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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ENGINEERING EXPERIMENT STATION

BULLETIN NO. 19 SEPTEMBER 1907

COMPARATIVE TESTS OF CARBON, METALLIZED CARBON AND TANTALUM FILAMENT LAMPS

BY T. H. AMRINE, B. S., FIRST ASSISTANT, DEPARTMENT OF ELECTRICAL ENGINEERING, ENGINEERING EXPERIMENT STATION

At the present time there are only three types of incandescent lamps having a wide enough commercial use to make them important factors in incandescent lighting. The first, and by far the most widely used, is the familiar carbon filament lamp, which in ordinary sizes gives an efficiency seldom exceeding 3.1 watts per candle power with an effective life of approximately 500 hours. The second type is also a carbon filament lamp, but the carbon by the process through which it passes in manufacture is given somewhat the characteristics of a metal, and for this reason is called the metallized filament lamp. The manufacturers have claimed for it an efficiency of about 2.5 watts per mean horizontal candle power. In the third type the filament is made of the metal tantalum and there is claimed for it an efficiency of about 2 watts per candle.

It is the purpose of this bulletin to give the results of tests made upon these lamps in the laboratory of the Electrical Engineering department of the University of Illinois, with the view of bringing out, if possible, the good points of each lamp together with any other facts that will help in the selection of the proper type for any particular purpose. Especial care was taken

The writer wishes to acknowledge his indebtedness to J. M. Bryant, Associate in Electrical Engineering, for valuable suggestions and co-operation; also, for aid in making the tests, to R. T. Calloway, L. G. Schumacher, O. M. Ward and W. R. Scott, of the Class of 1907 in Electrical Engineering.

throughout all the work to make the conditions under which the tests were conducted exactly the same for each type of lamp in order to have a fair basis of comparison between types. Although comparative rather than absolute results have been particularly striven for it is felt that dependable quantitative values have been obtained.

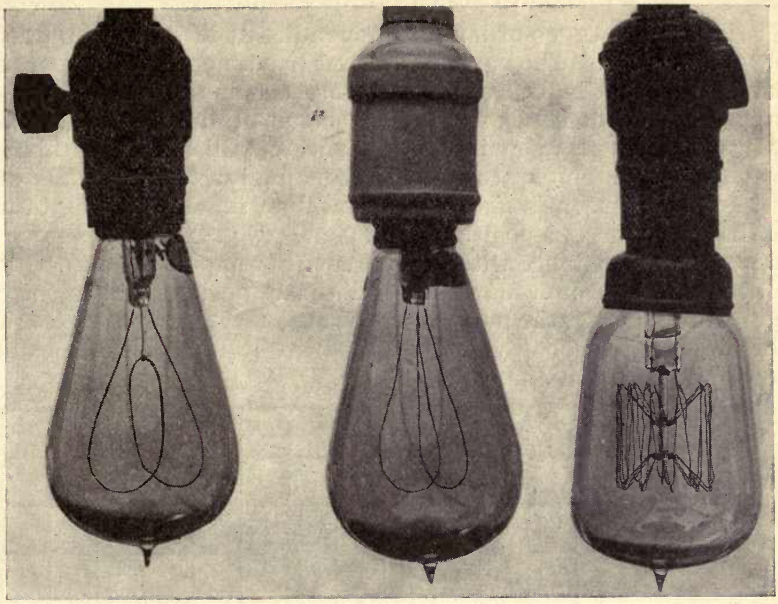
DESCRIPTION OF LAMPS*

The lamps chosen for the tests were selected from a lot of 100 of each type of lamp. These were bought directly from the manufacturer, a well known and reliable incandescent lamp company.

Ratings.—The carbon lamp was rated by the manufacturer at 25 candle power at 110 volts with an efficiency of 3.1 watts per candle. The metallized filament lamps were rated at 50 watts at 110 volts, no mention being made of candle power on label. The tantalum lamps had a rating of 22 candle power at 110 volts.

Filaments.—The filaments of the carbon lamp were of the familiar single-loop type anchored in the middle of the loop. They had a smooth uniform appearance and were of the steel-gray color common to all properly flashed carbon filaments. The filaments of the metallized lamp were not so smooth in appearance as those of the carbon lamp. They had a kinked appearance, which, according to the statement of the manufacturer, was due to the method of treating the filament and in no way affected the efficiency of the lamp. The color was steel gray, slightly darker than the carbon filament. The filaments were double, consisting of two horseshoe loops, the inside ends of which were attached to a common anchor. The tantalum filaments were very fine and long, as was necessitated by the rather low specific resistance of the metal tantalum. They were mounted in the well known zigzag fashion upon supporting spires. The color was a silver-gray with a metallic luster. Fig. 1 is a photograph of the three types of lamps used in the tests. Table 1 gives the approximate effective dimensions of the three types of filaments.

* At the time these tests were started, tungsten lamps could not be purchased on the market. In the matter of current consumption, life and candle power maintenance these lamps seem much superior to the three kinds tested. The manufacturers claim an efficiency of 1 watt per candle with a life of 1000 hours with a decrease in candle power of only 10 per cent. However, as is the case with the tantalum lamps, they are rather delicate and require even more careful handling.



CARBON METALLIZED TANTALUM

FIG. 1

TABLE 1

Filament	Effective Length inches	Mean Diameter	Effective Area square inches
Carbon	9.4	.0060	.1774
Metallized	9.5	.0037	.1108
Tantalum	23.4	.0018	.1324

Bulbs.—The shapes of the bulbs and their comparative sizes are shown in Fig. 1. Those of the carbon and metallized lamps are of the same size and shape, having a length over all of 5 $\frac{1}{16}$ in., a maximum diameter of $2\frac{3}{8}$ in. and a minimum diameter of $1\frac{1}{8}$ in. The tantalum lamp is about $5\frac{1}{8}$ in. in length and has a maximum diameter of $2\frac{11}{32}$ in. tapering to a minimum diameter of $1\frac{15}{16}$ in., thus making the sides much more nearly parallel than in the case of the carbon and metallized lamps.

Electrical Characteristics

The three types of lamps differ radically in their temperature characteristics. The carbon filament has a negative temperature coefficient; that is, its resistance decreases as the temperature increases. On the other hand, on account of the treatment which it has undergone in manufacture, the metallized carbon filament has a positive temperature coefficient similar to the metals when in the incandescent stage. The tantalum filament, being of metal, has, of course, a positive coefficient. Fig. 2 plainly shows the increase of resistance with the increase of temperature in the metallized and tantalum filaments and the opposite effect in the carbon after reaching the incandescent stage. At lower temperatures the change is probably greater than after it becomes incandescent, especially in the carbon lamp.

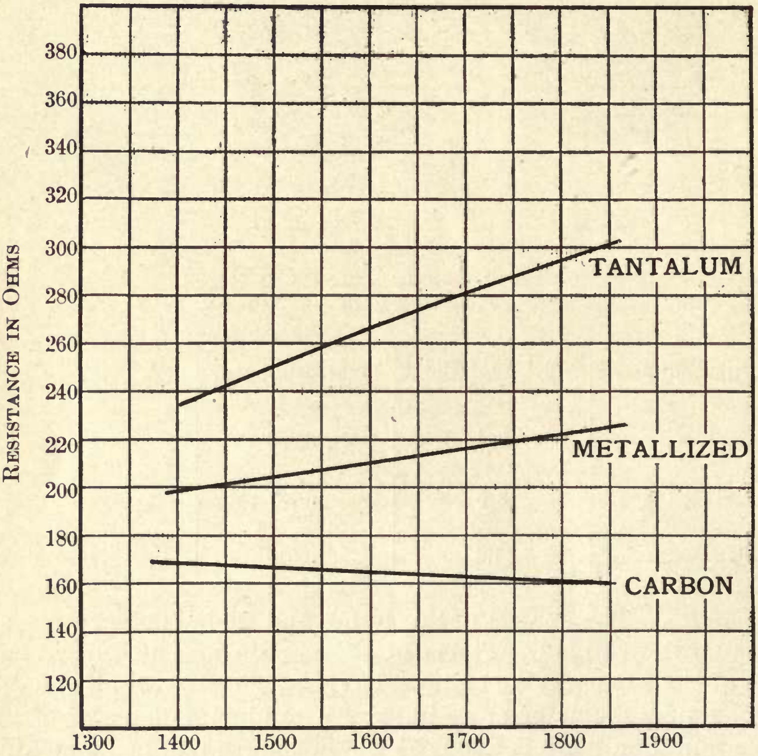


Fig. 2 Filament Temperature, Degrees Cent.

As a result of the positive coefficients of the metallized and tantalum filaments, the lamps flash up to full incandescence much more quickly than the carbon lamp. When the current is turned on, the filament, being cold, has a low resistance and there is a rush of current considerably above normal. This excessive current is rapidly cut down as the lamp reaches incandescence on account of the increase in resistance. The carbon lamp, having the greatest resistance when cold, allows but a comparatively small current to pass at first, but gradually allows it to increase as the resistance becomes less. This is beautifully shown by the oscillograms of the rise in current in the three lamps shown in Fig. 3. With the carbon lamp it is seen that the current almost

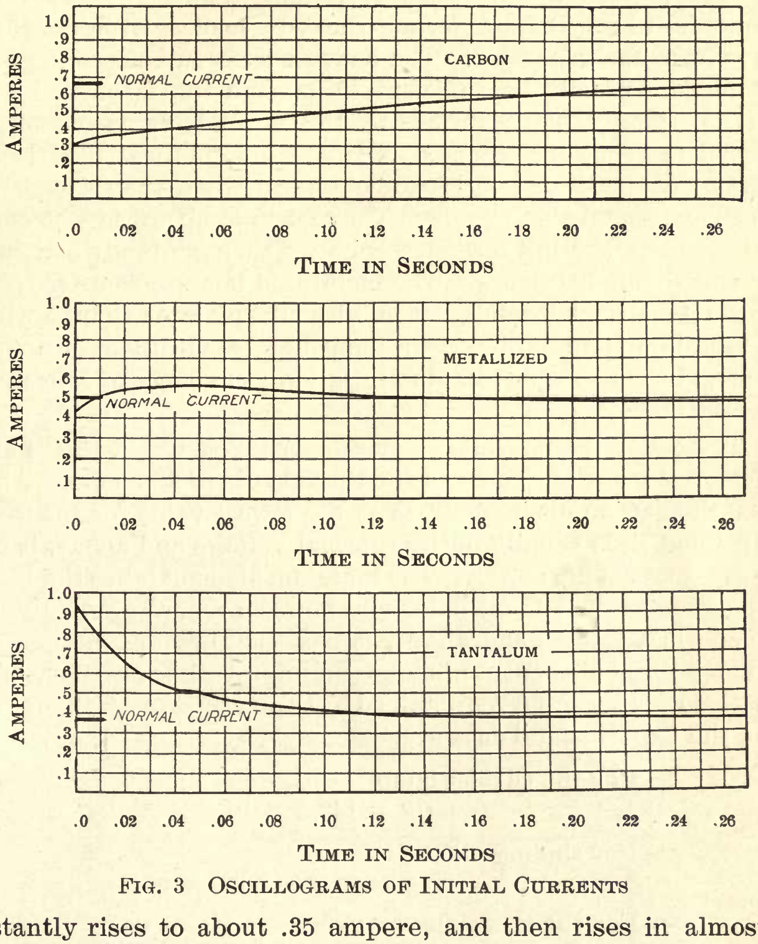


FIG. 3 OSCILLOGRAMS OF INITIAL CURRENTS

instantly rises to about .35 ampere, and then rises in almost a straight line to the full steady value of current in about .26 second. With the metallized lamp the current rises at once to about .45 ampere, almost the full steady current, then increases to a maximum value of .55 ampere in approximately .05 second, indicating a negative temperature coefficient at the lower temperatures. It then decreases gradually to the normal steady value in about .16 second. The curve for the tantalum lamp indicates that a rush of current takes place as soon as the circuit is closed, reaching a maximum of about .93 ampere, almost three times the full steady current, practically instantaneously. This rush of current in the tantalum lamp will probably require that some precautions be observed in switching feeders heavily loaded with tantalum lamps on to the generator. The heavy excess current at the first instant might easily be sufficient to damage the machine. The current then rapidly drops to the normal value which is reached in about .14 second. A suggestion of these differences of action of the three lamps can be noticed when they are simultaneously lighted side by side. The carbon lamp appears to come at once to a rather dull incandescence and then gradually increases to its maximum brilliancy. The metallized lamp appears to reach at once its normal incandescence without any later change while the tantalum lamp bursts forth immediately in brilliant incandescence and then subsides gradually, giving the effect of a flash at the first instant.

The candle power voltage characteristic curves in Fig. 4 also show important differences in the three types of filaments. At 80 volts, the carbon filament starts at the lowest value for the three lamps, and rises rapidly until at normal voltage and above, it has the greatest candle power. The tantalum filament takes the highest position at the 80-volt point and increases more gradually until at normal voltage and above, it has the lowest candle power. The metallized filament curve takes an intermediate position. The equations for these curves obtained by the method of least squares from the experimental data are:

For the carbon lamp

$$CP = 143.5 \times 10^{-13} \times E^{5.97}$$

For the metallized lamp

$$CP = 50.7 \times 10^{-11} \times E^{5.20}$$

For the tantalum lamp

$$CP = 166.4 \times 10^{-10} \times E^{4.45}$$

Below is shown a table exhibiting the change in candle power for an increase of 5 per cent in the voltage and for a decrease of 5 per cent in voltage from the normal.

TABLE 2

Lamp	C. P. Increase for Five per cent Increase in Voltage above Normal	C. P. Decrease for Five per cent Decrease in Voltage below Normal
Carbon	7.3 or 33.2 per cent	6.8 or 31.0 per cent
Metallized	5.6 or 25.7 per cent	5.8 or 27.6 per cent
Tantalum	4.4 or 22.0 per cent	4.8 or 24.0 per cent

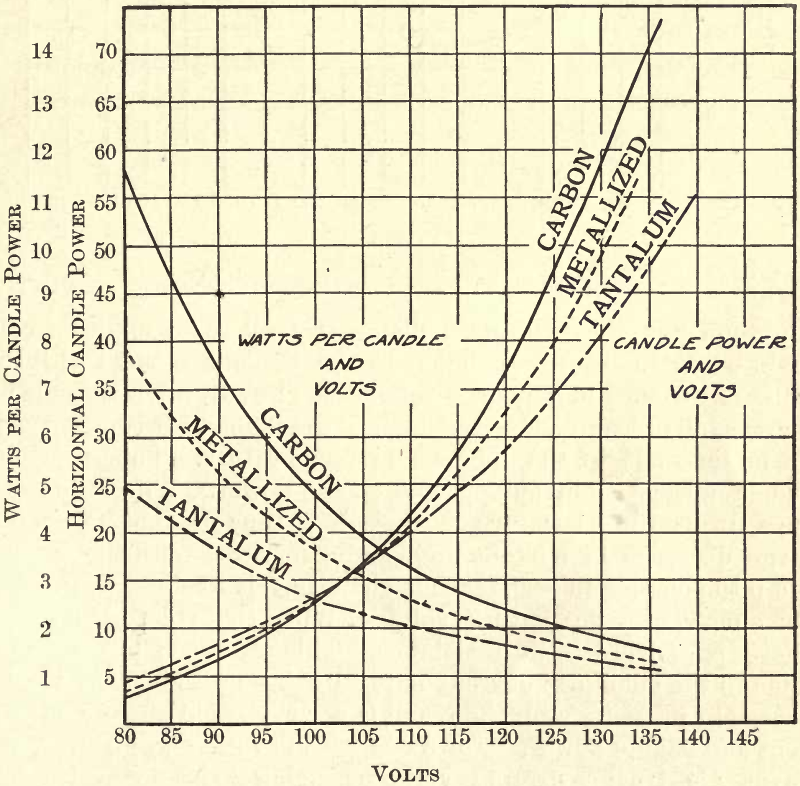


FIG. 4 CHARACTERISTIC CURVES OF CANDLE POWER AND WATTS PER CANDLE

The change in efficiency or watts per candle is also shown in Fig. 4, indicating a wide difference in favor of the tantalum lamp throughout the range of voltage. The curves showing the change of resistance with the voltage (Fig. 5) indicate that the

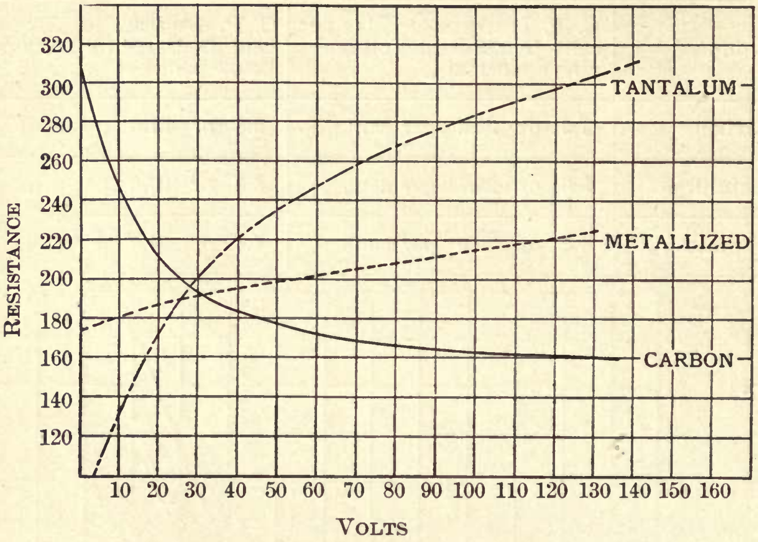


FIG. 5 CURVES SHOWING CHANGE OF RESISTANCE WITH VOLTAGE

tantalum and the metallized filaments tend to regulate for constant current. In these filaments the resistance rises with the voltage. Hence in a poorly regulated circuit, when there is an increase in pressure, the resistance of the filament becomes greater on account of the increase in temperature. This prevents such a great rise in current and candle power. When the pressure drops the resistance is decreased, thus preventing such a large decrease in current and candle power. With the carbon lamp the change in resistance is such that it tends to aggravate the effects of a fluctuating voltage. When the voltage increases there is a decrease in resistance. This decrease in resistance adds to the change in current naturally brought about by the increase in pressure and the result is a very rapid change in current and candle power. For a decrease in voltage, of course, the reverse is true; a drop in voltage causing a rise in resistance, the change in both of them being in the direction to decrease the current and candle power.

Distribution

Horizontal and vertical distribution curves for the different lamps when new and after 800 hours of burning are shown in Fig. 6 to 14. The small figure below each set of curves indicates the position of the filament in each case. The horizontal distribution in all three lamps evidently changes equally in all directions after a period of burning. That for the tantalum lamp would be almost a circle except for the influence of the leading-in wires. These cause a minimum point on the side nearest to them. The vertical distribution of the carbon and metallized lamps changes but little after 800 hours of service. That of the tantalum, however, changes to a marked extent; the candle power for the position 30° from the tip of the lamp being greater after burning the 800 hours than when new. The change in the spherical reduction factor (the constant for changing mean horizontal candle power to mean spherical candle power) of the lamps during their life gives a good indication of the way the distribution changes. Following is a table of these values for three periods of life.

TABLE 3

Lamp	Spherical Reduction Factors		
	New	400 Hours	800 Hours
Carbon	.810	.805	.794
Metallized	.803	.805	.801
Tantalum	.787	.811	.865

The causes of this change in the distribution of the intensity in the tantalum lamp must be due principally to the change in the character of the surface of the filament after burning. The microphotographs of the filaments shown in Fig. 30 indicate how roughened and pitted they become after burning for a few hundred hours. The irregularities of the surface cause the light to be radiated and reflected from their surfaces more and more in a direction parallel with the length of the filament as the period of burning increases. This, of course, shifts the maximum of in-

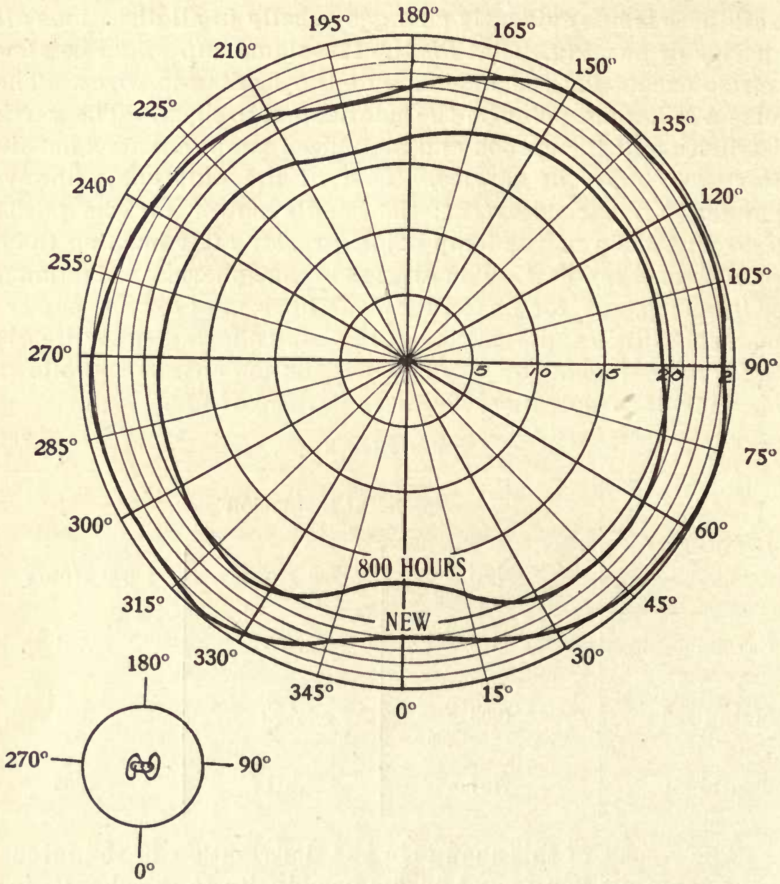


FIG. 6 HORIZONTAL DISTRIBUTION OF CARBON LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

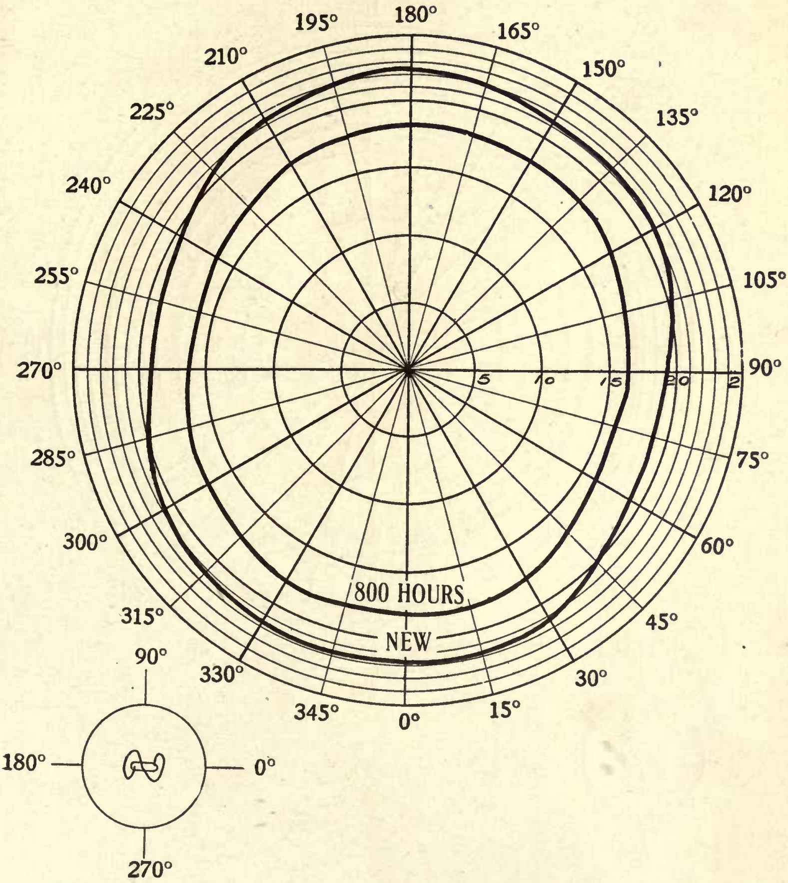


FIG. 7 HORIZONTAL DISTRIBUTION OF METALLIZED LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

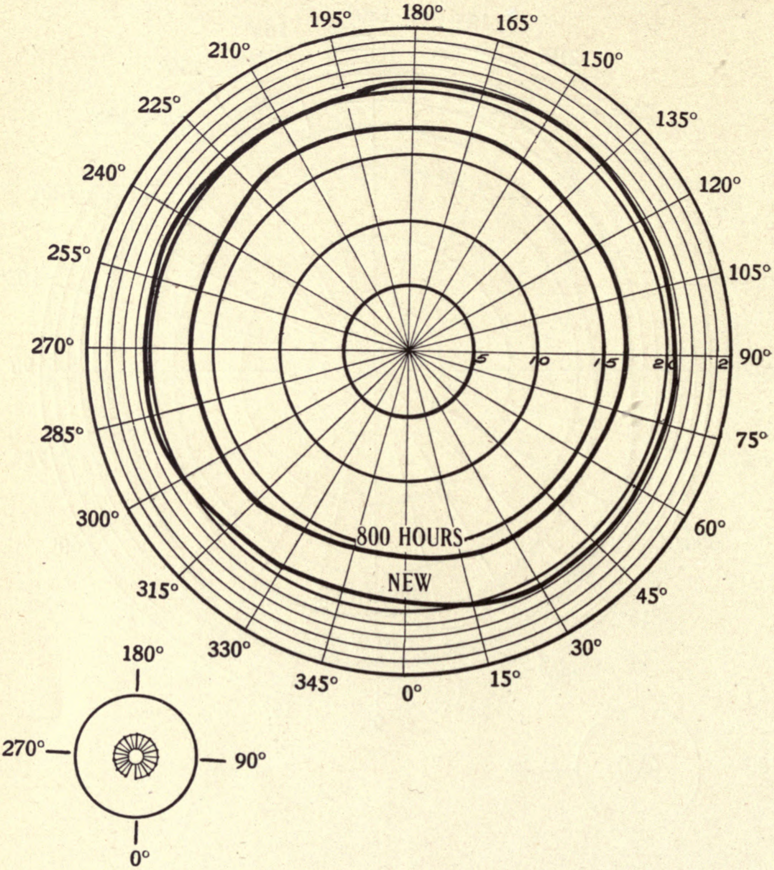


FIG. 8 HORIZONTAL DISTRIBUTION OF TANTALUM LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

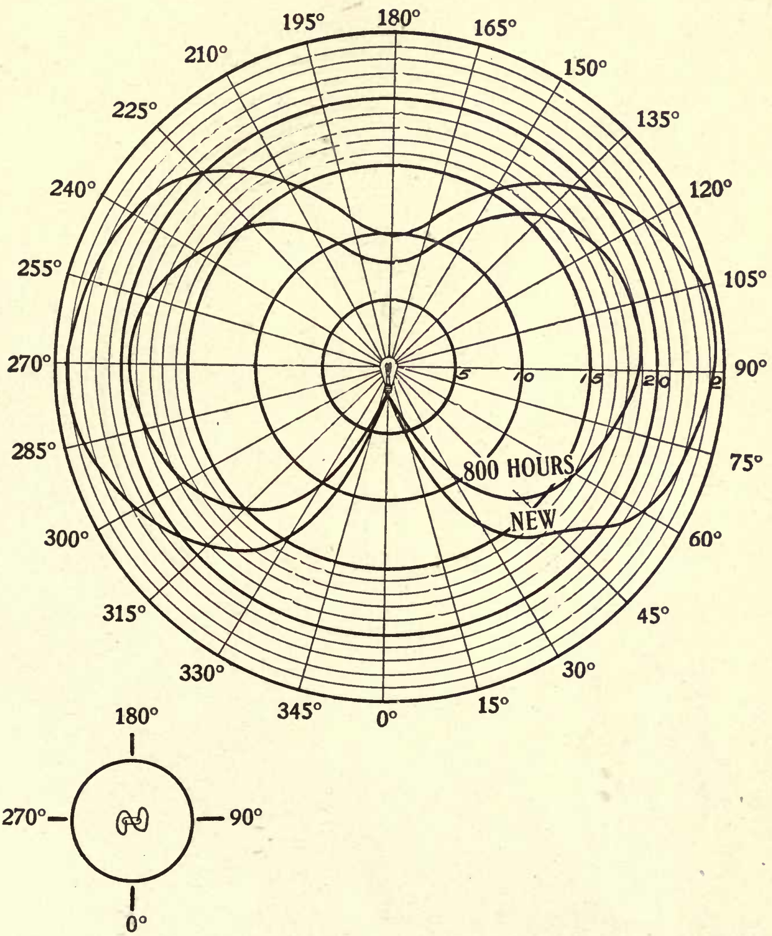


FIG. 9 VERTICAL DISTRIBUTION AT 90° AZIMUTH OF CARBON LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

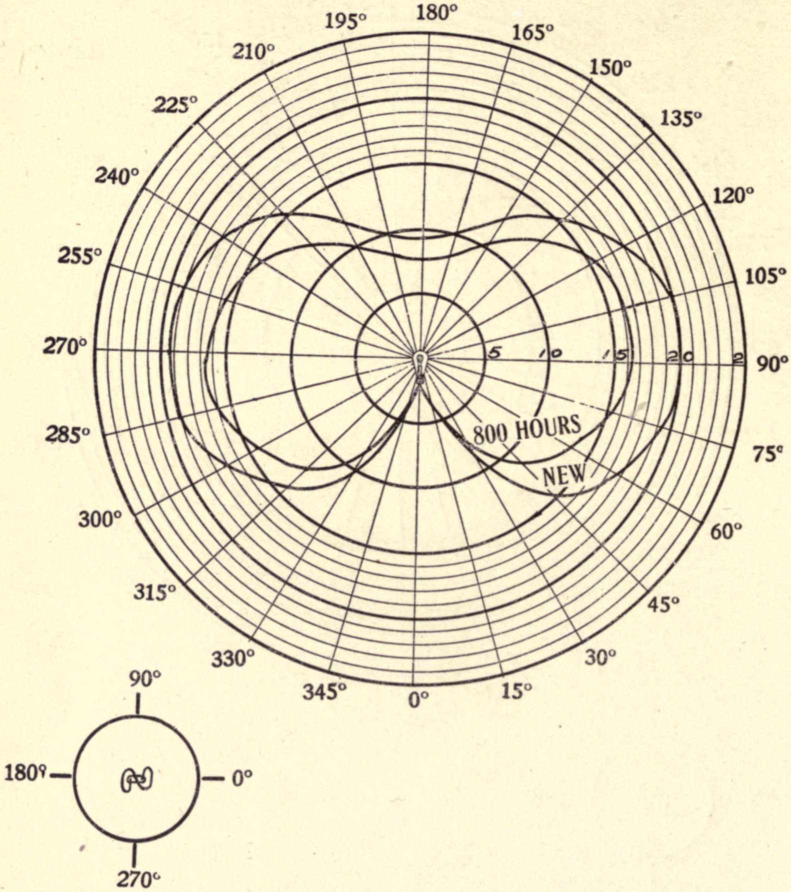


FIG. 10 VERTICAL DISTRIBUTION AT 90° AZIMUTH OF METALLIZED LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

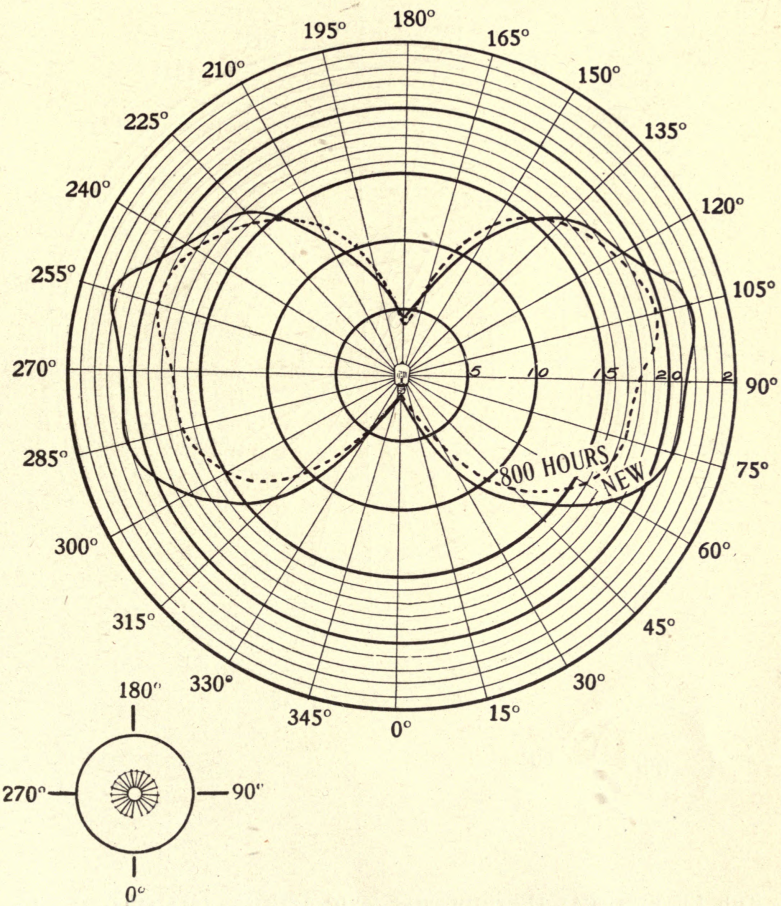


FIG. 11 VERTICAL DISTRIBUTION AT 90° AZIMUTH OF TANTALUM LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

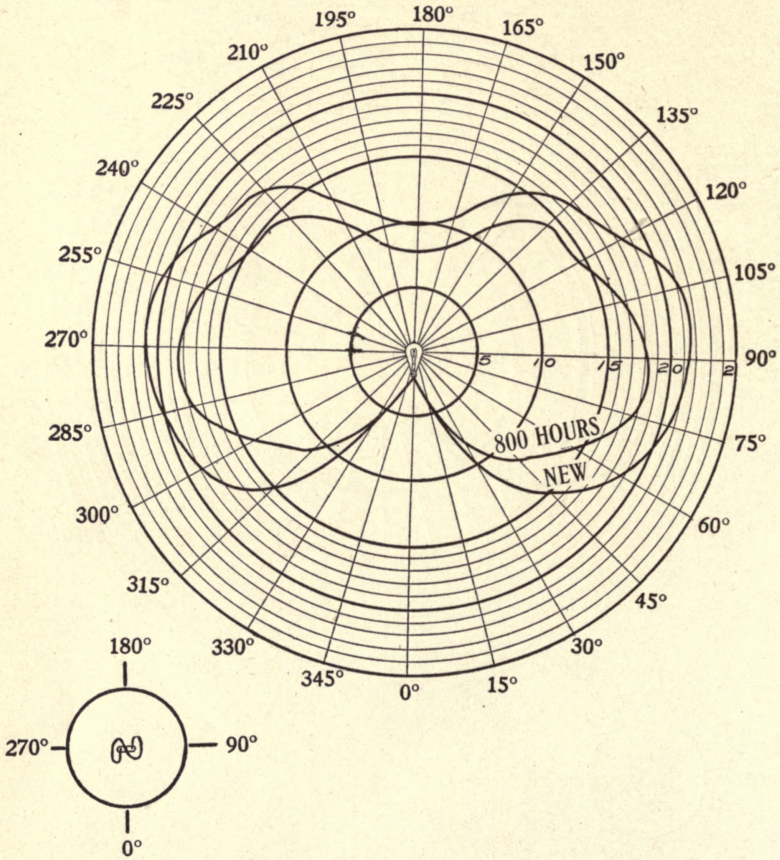


FIG. 12 VERTICAL DISTRIBUTION AT 0° AZIMUTH OF CARBON LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

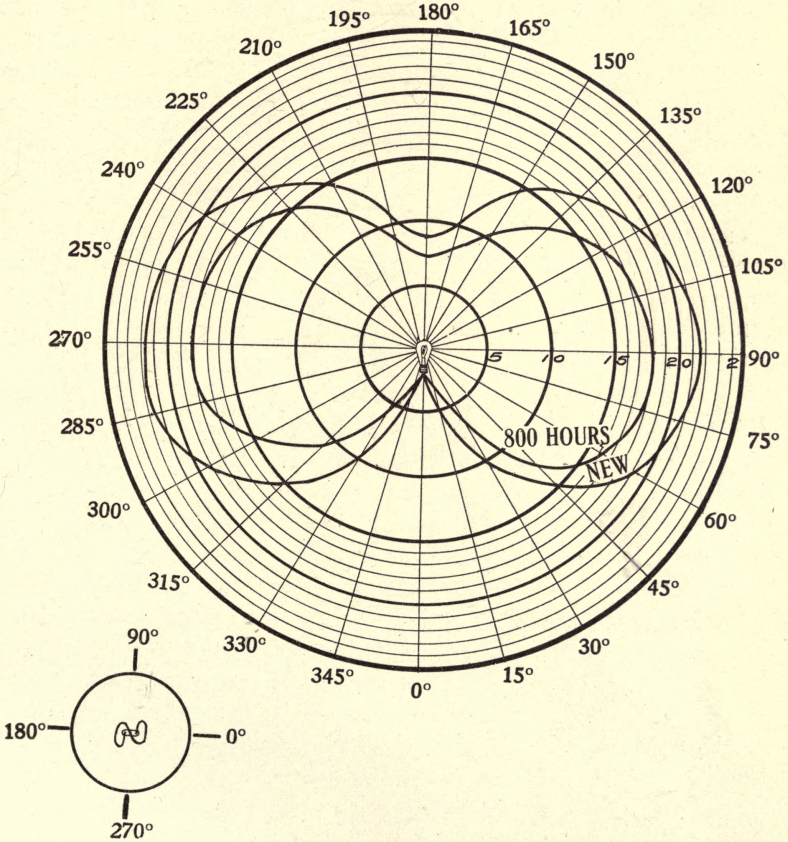


FIG. 13 VERTICAL DISTRIBUTION AT 0° AZIMUTH METALLIZED LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

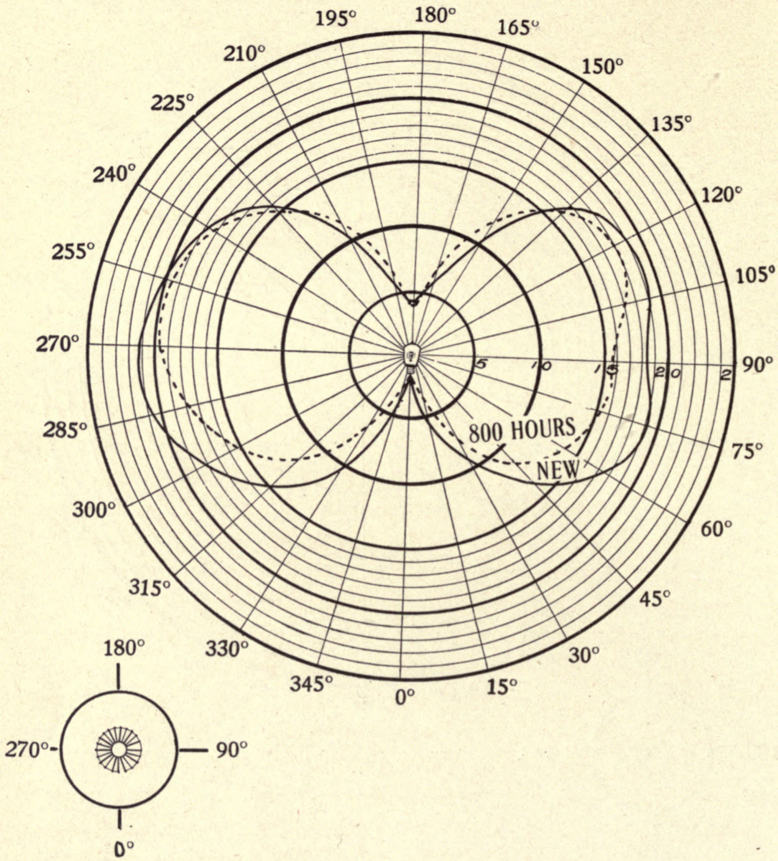


FIG. 14 VERTICAL DISTRIBUTION AT 0° AZIMUTH OF TANTALUM LAMP WHEN NEW AND AFTER 800 HOURS OF BURNING

tensity of the vertical distribution curves further from the horizontal. In the carbon and metallized filaments there is but little change in the character of the surface, and consequently the distribution in these lamps changes but little from this cause. The manner in which the bulb of the tantalum lamp discolors after use will also partly explain the cause of the change in distribution. This discoloration takes the form of a band of black deposit on the glass, equal in width to the distance between the top and bottom supporting spires. Outside of this band there is a deposit, but it is much lighter. It is as if the particles of the metal were projected from the incandescent filament only in directions normal to its surface. The density of this deposit in the band cuts down the horizontal intensity a great deal, but at the tip, where the deposit is thinner, the candle power is decreased by a much less amount.

Life Tests

Life tests were made of the three kinds of lamps under two different conditions. Ten lamps of each kind were put through the life and efficiency test upon a steady, well-regulated voltage supplied by a storage battery. The battery was kept floating across nearly constant voltage mains and a large rheostat was put in series with the lamps with which to make the finer adjustments by hand. The maximum variation was probably not more than one volt and the greater portion of the time the voltage was as nearly correct as the portable voltmeter used would indicate. This was designated "Condition A" and represents the best conditions under which the lamps would ever be operated in practice. The same number of lamps were operated under adverse conditions. A badly fluctuating alternating current was supplied to the lamps and there was considerable vibration. This condition, designated "Condition B", is representative of very bad operating conditions. Fig. 15 to 20 show the candle power performance of each lamp in the test. The uniformity of the lamps under condition A is noticeable, none of the curves varying greatly from the mean.

Burn-outs and Failures.—In the 800 hours of the test under condition A only three lamps were lost. Of the two tantalum lamps lost, one failed by the breaking of the glass stem and the leading-in wire, probably due to the expansion of the latter. The other failed in 30 hours probably on account of a fault in the filament. It was repaired and it then burned at a high candle power for a short time and then burned out. The failure of metallized filament lamp No. 2 was due to the fact that the filaments be-

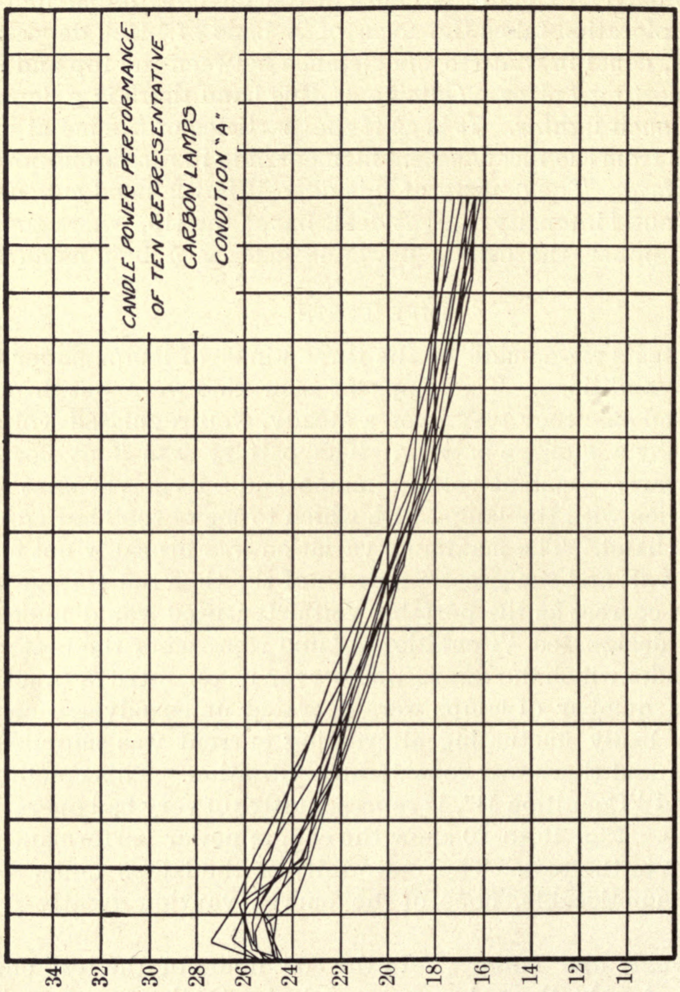


FIG. 15 LIFE IN HOURS

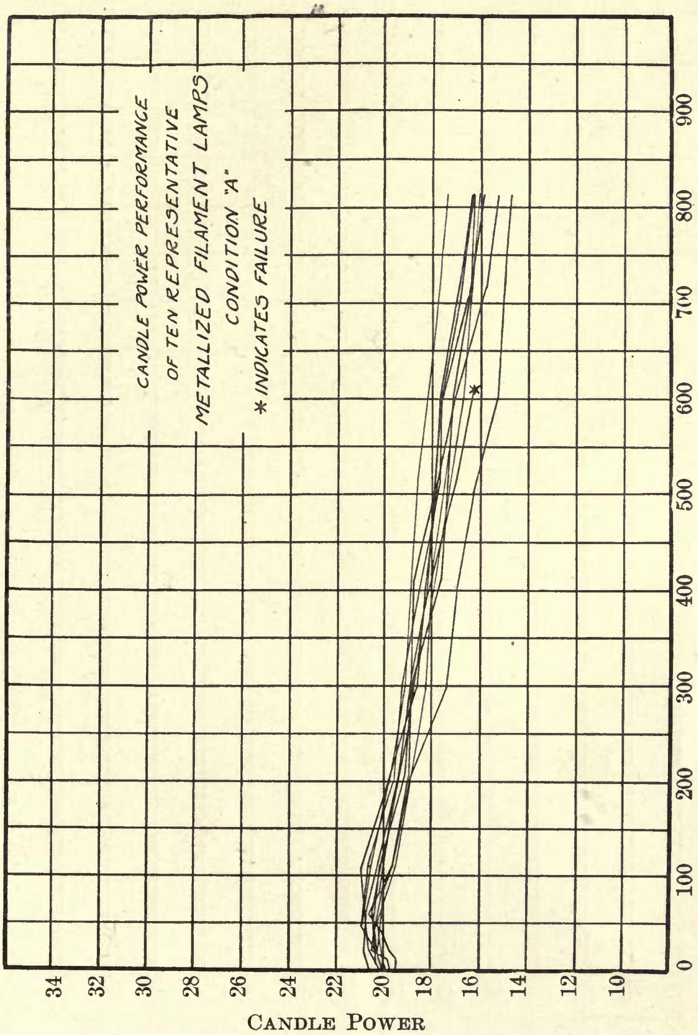


FIG. 16 LIFE IN HOURS

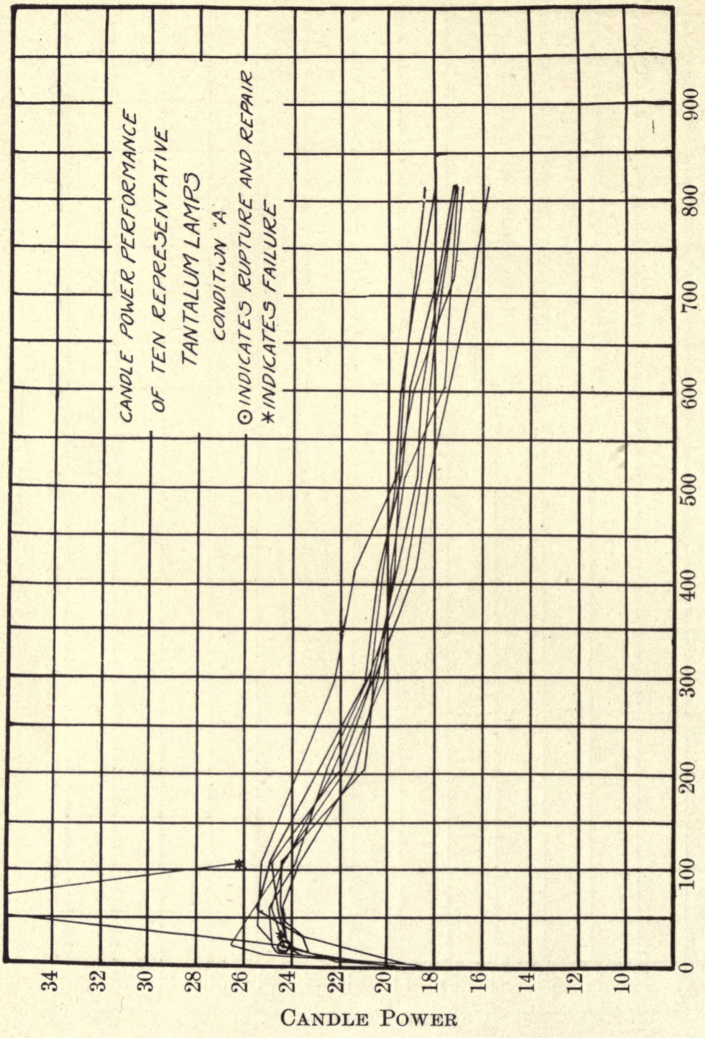


FIG. 17 LIFE IN HOURS

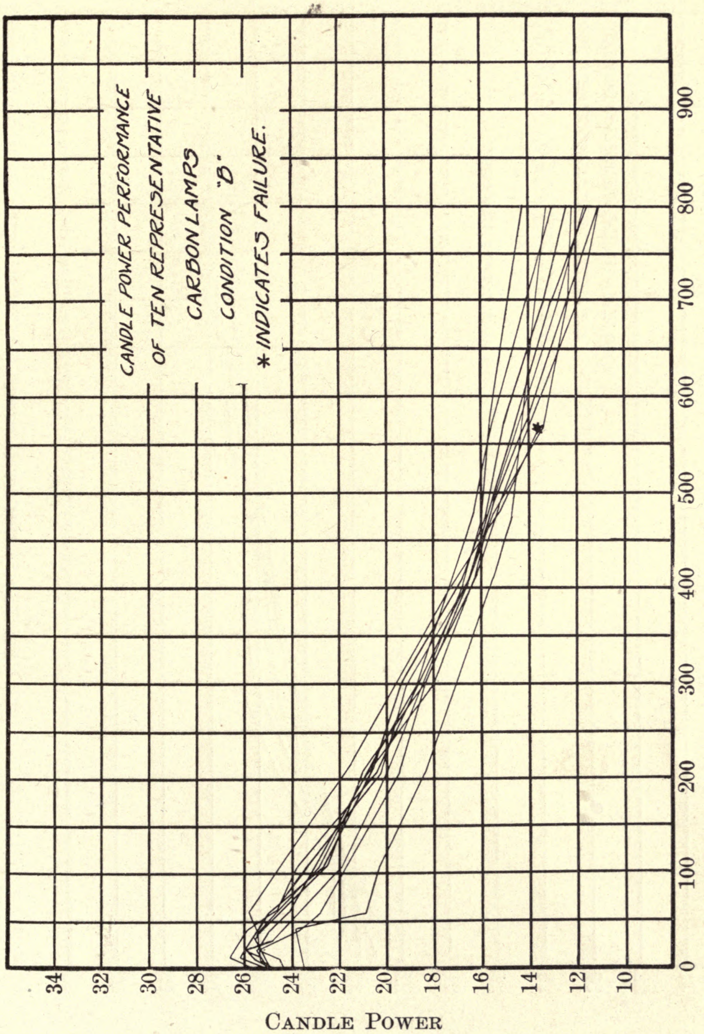


FIG. 18 LIFE IN HOURS

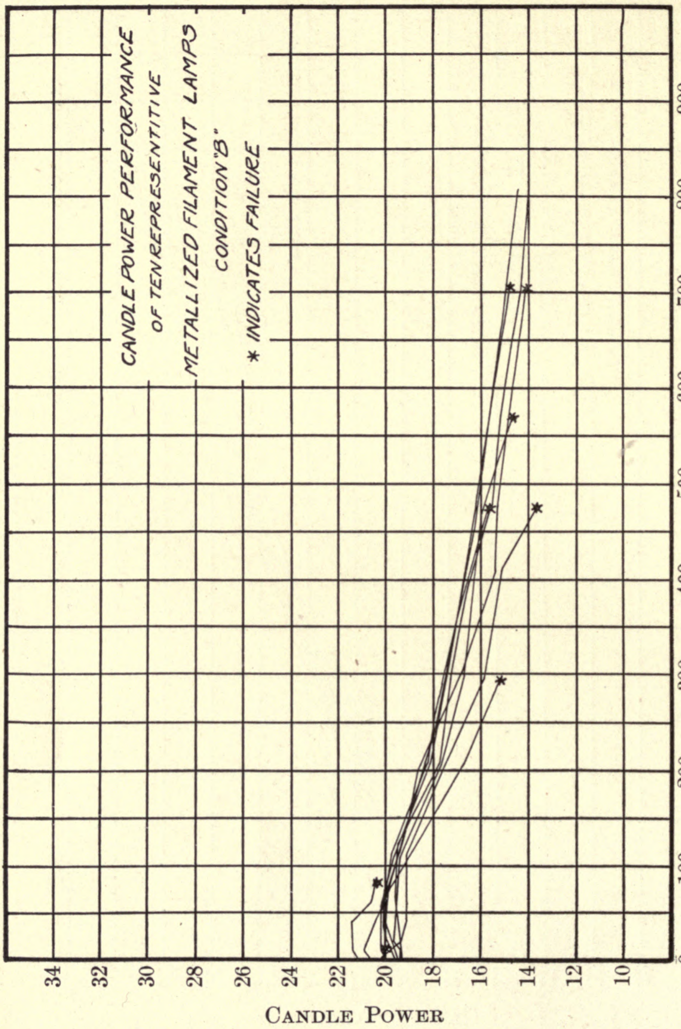


FIG. 19 LIFE IN HOURS

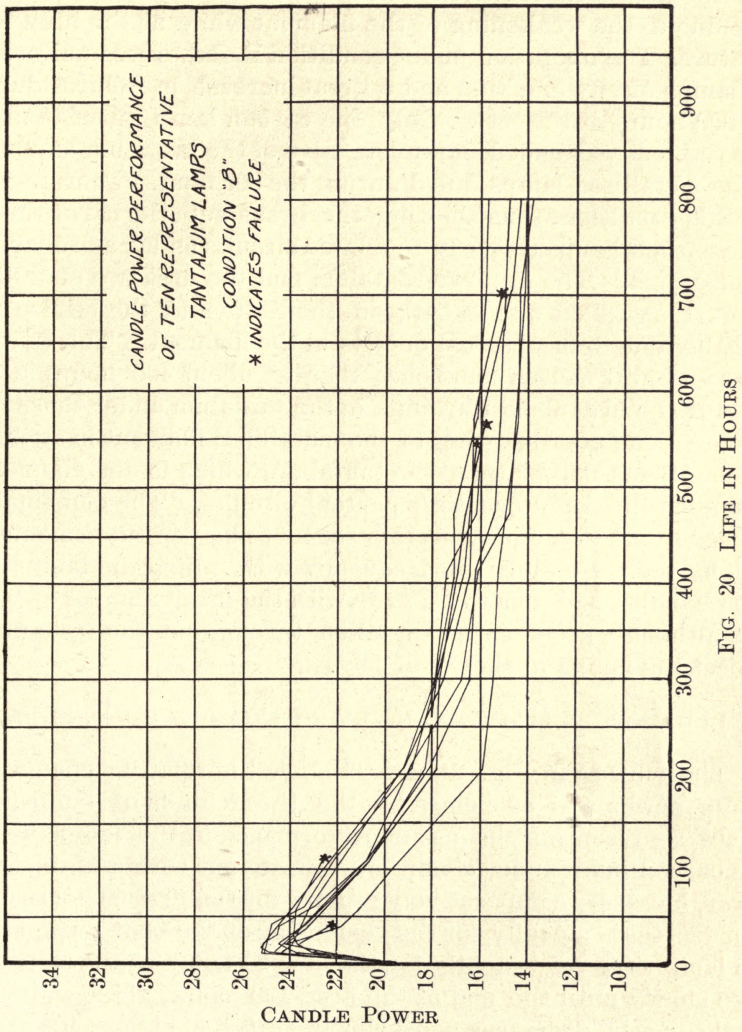

CANDLE POWER PERFORMANCE
OF TEN REPRESENTATIVE
TANTALUM LAMPS
CONDITION "B"
* INDICATES FAILURE
Candle Power
34
32
30
28
26
24
22
20
18
16
14
12
10
Life in Hours
0
100
200
300
400
500
600
700
800
900

Fig. 20

came crossed in placing the lamp in the socket. Naturally it burned at a very high brilliancy until the lamp could be removed from the socket and the cross shaken out. When this was done and the lamp returned to its place, it burned out in a very short time due to the weakening of the filament while at the high temperature. The operation under condition B shows less uniformity for lamps of any one kind and a great increase in failures during the 800 hours of the test. Only one carbon lamp burned out before the test was ended, however. Five of the tantalum and eight of the metallized lamps failed during the 800 hours of burning under this condition, thus showing the great superiority of the old style carbon lamp on poorly regulated circuits as far as reliability is concerned. The first two tantalum and the first two metallized lamps that failed did so early in their life and the failure was probably due to mechanical defects in the filament. The failures due to natural causes commence then at about 400 hours in the metallized and at about 550 hours in the tantalum under these conditions. The poor showing of the metallized filament is striking, it being much poorer than the tantalum, which is not claimed to give good life on alternating current circuits. The combination of poor regulation and vibration seems to be very detrimental to its long life. Possibly the frequency with which the lamps had to be handled had something to do with the large number of burnouts although great care was taken throughout the tests not to subject the lamps to shocks or jars.

Candle Power Maintenance and Change of Efficiency

The curves in Fig. 21 and 22 show the relative changes of candle power and efficiency for the three kinds of lamps, the curves representing the mean performance of the lamps tested. The carbon lamp under condition A starts out with a high candle power, increases comparatively rapidly for the first 50 hours or so then decreases steadily for the remainder of the test. The tantalum lamp rises very rapidly for the first 20 hours of the test, then more slowly until the end of the first 100 hours, after which the candle power decreases more slowly, after 400 hours its candle power being greater than that of the carbon. The metallized lamp changes less than either of the others. It rises during the early period of burning, remains almost constant for a time, decreasing slowly in candle power during the remainder of its life.

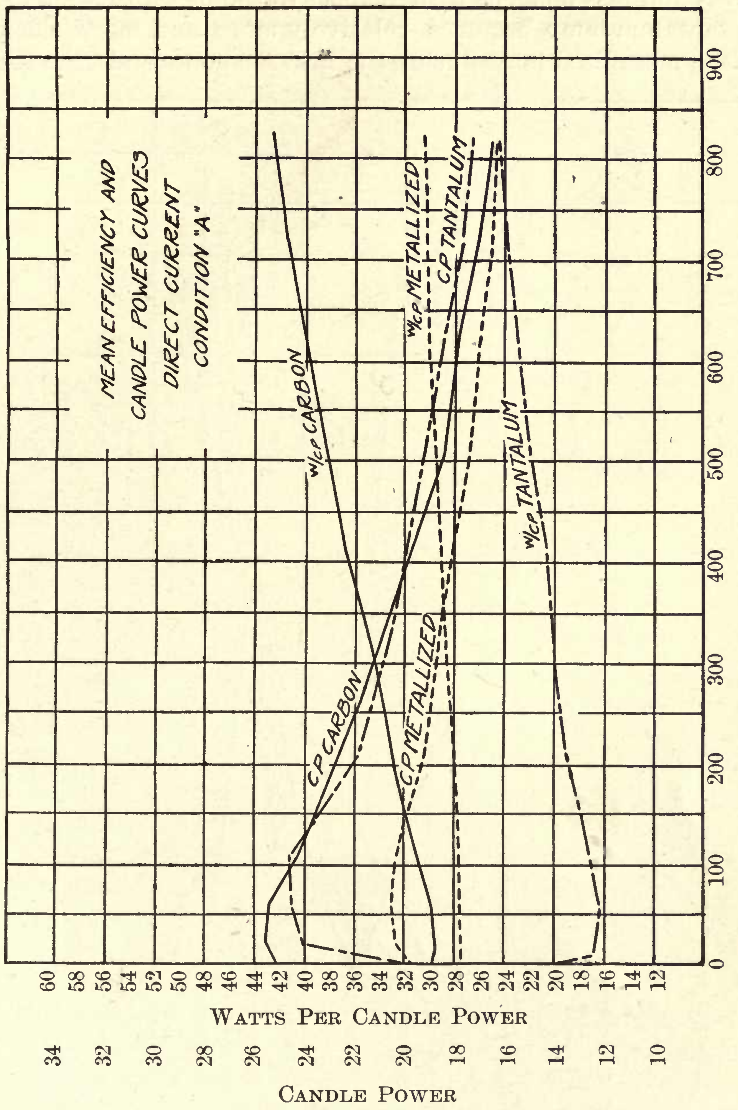


FIG. 21 LIFE IN HOURS

The metallized lamp changes no more in efficiency than it does in candle power. The carbon lamp changes rapidly, becoming less and less efficient with respect to the metallized filament. The tantalum lamp becomes relatively more and more efficient than the metallized lamp during the first 250 hours and then tends

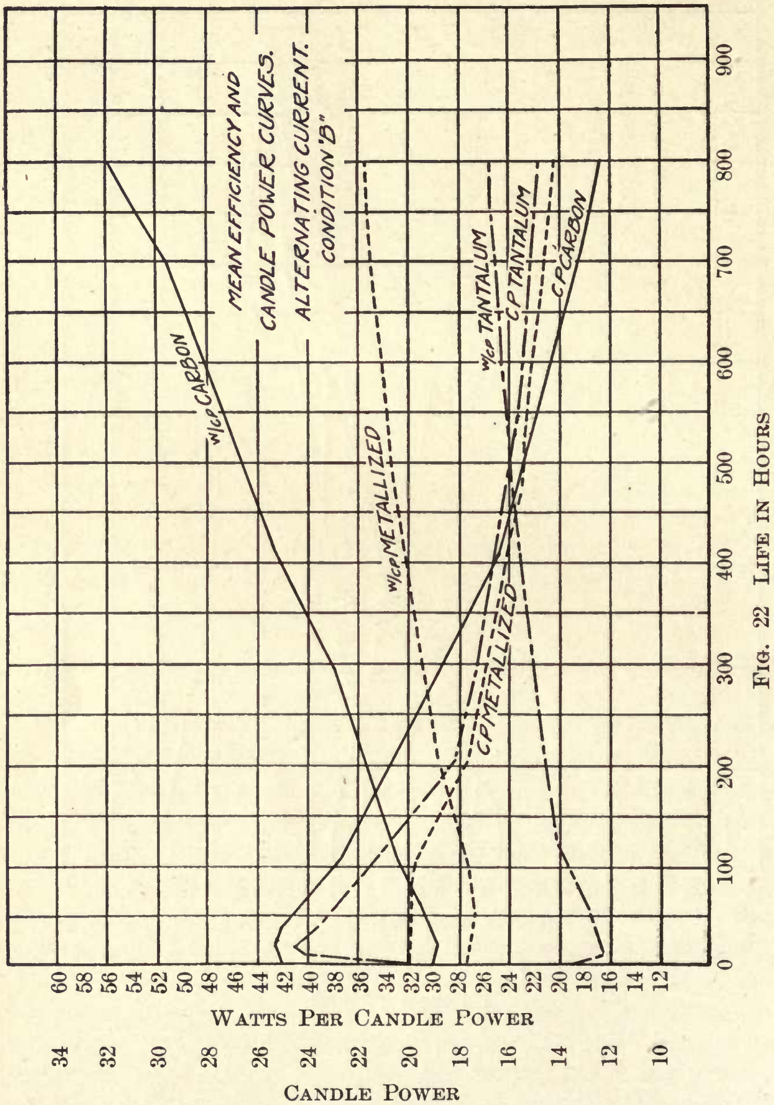


Fig. 22

to drop off and approach it in efficiency. When operating under condition B the changes in candle power and efficiency are much the same except that the changes occur more rapidly. It is noticeable that in this case the carbon lamp starts out with the highest candle power, but after 500 hours of burning it has the lowest. Its decrease in efficiency is correspondingly rapid. Under condition B the tantalum lamp no longer becomes less efficient relatively to the metallized lamp as the period of burning increases as it does under condition A. Its efficiency curve tends to fall further and further below that of the metallized lamp.

The reason why the tantalum and metallized filament lamps show a better efficiency than the carbon is of considerable interest. There is no doubt that the greater amount of the superior efficiency of the newer types of lamps is due to higher filament temperatures. As is well known, when a solid body is heated, at first only the long, low frequency heat waves appear, then the red light waves, and as the temperature is further increased, wave lengths corresponding to the other colors of the spectrum through the violet and ultraviolet appear. If for any temperature we measure by means of the bolometer the intensity of radiation at points throughout the visible and invisible portions of the spectrum and plot these values against the wave lengths, we get a curve similar to curve A in Fig. 23, having a maximum at some point, *m*. The visible, that is, the light-giving portion is shown unshaded. As the temperature is increased, the maximum of this curve moves toward the region of shorter wave lengths, as shown in the curve B. There is, however, an increase in the length of each ordinate so that the curve does not move bodily down the spectrum with an increase in temperature, but the ordinates of the energy curve move toward the shorter wave lengths by an amount such that the product of the corresponding abscissas and the temperature remains constant for each ordinate. It is seen then that the visible portion of the spectrum is a greater proportion of the entire spectrum than at the lower temperature and hence a better light efficiency results. If we remember that the velocity with which the molecules of a body are moving increases with the temperature, then we can in a general way see why it is that the point of maximum intensity in a continuous spectrum is shifted toward the violet as the temperature increases.

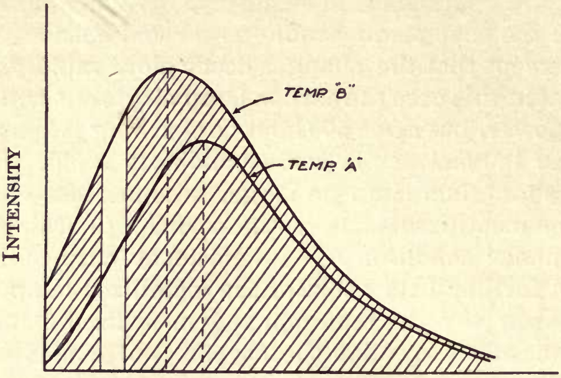


FIG. 23 WAVE LENGTH

The curves between temperature and candle power per square inch of filament area, or emissivity, shown in Fig. 24, indicate that the tantalum filament has a lower and the metallized a higher emissivity than the carbon filament. Since emissivity is vitally connected with the light efficiency of an incandescent body, the difference in the relative positions of the emissivity curves of the metallized and tantalum lamps with respect to the carbon seems to indicate that a part of the better efficiency of the two newer filaments is due to different causes.

The tantalum filament, having a lower emissivity than the carbon filament, requires less energy to maintain the same temperature than the carbon; that is, the lower emissivity of the tantalum filament gives it a better efficiency than the carbon at the same temperature. This is in addition to the fact that tantalum has a greater atomic weight and a higher vapor tension point than carbon, thus allowing it to be operated at a higher temperature with the consequent better efficiency.

Since the metallized filament has a higher emissivity than the carbon filament it must require a greater input of energy per square inch of surface to maintain a given temperature. Experiment shows that the input of the metallized lamp is about 460 watts and the carbon about 410 watts per square inch of filament area at a temperature 1720° C. To give, as it does even at equal temperatures, a better watt per candle efficiency it must then give off a greater proportion of light energy to heat energy than the carbon lamp. Since the carbon filament is approximately though

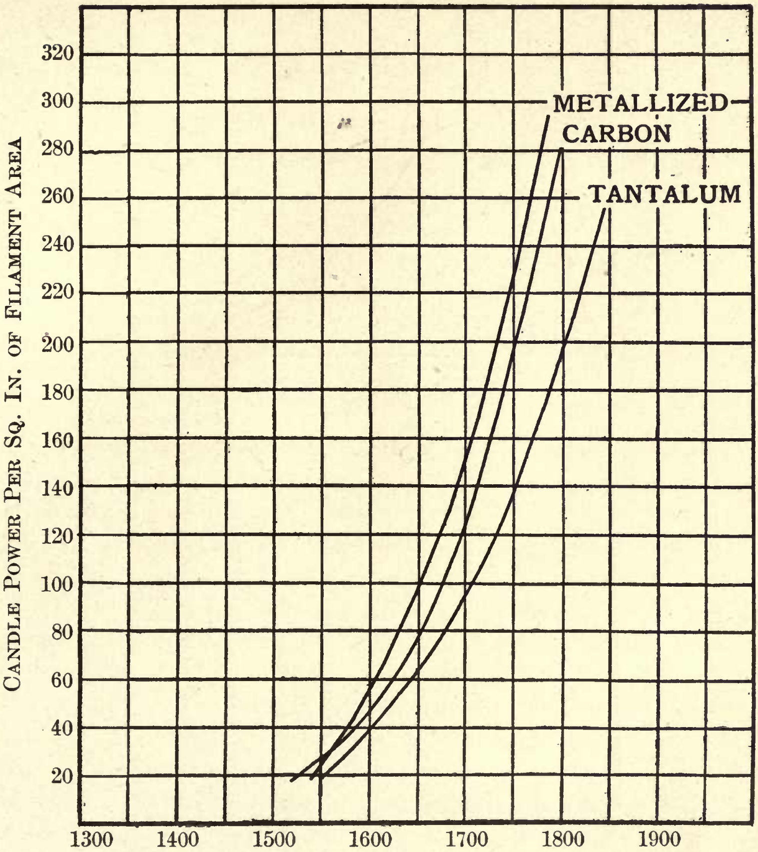


FIG. 24 FILAMENT TEMPERATURE, DEGREES CENT.

only approximately, equivalent to the theoretical solid black body this fact seems to show that the greater efficiency of the metallized filament must be due, at least in part, to a sort of selective radiation. That is, it radiates either a greater proportion of its energy within the range of the visible spectrum than a black body or a smaller proportion in the invisible range. In Fig. 25 and 26 the dotted curves show the radiation from a solid black body. Fig. 25 shows the curve for a body having at the same temperature almost the same radiation outside the visible spectrum but a much greater radiation within, while in Fig. 26 is shown the curve for a body having practically the same radiation within the

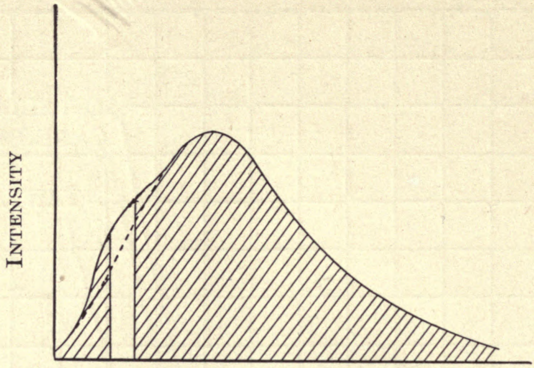


FIG. 25 WAVE LENGTH

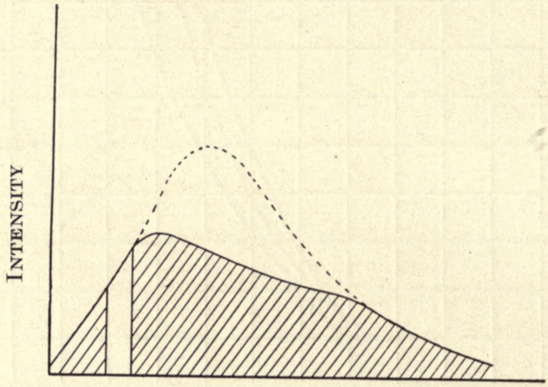


FIG. 26 WAVE LENGTH

visible portion of the spectrum, but a much less radiation without than in the case of a black body. In one of these cases the metallized filament, no doubt, falls. In both cases, however, there is an increase in efficiency due to selective radiation.

In the curves between watts per candle and filament temperature, there is another indication that the high efficiency of the metallized and tantalum lamps is due to different causes. It is seen in the curves of Fig. 27 that at ordinary efficiencies the tantalum is the lowest, the metallized next, while the carbon is the highest. However, at about 1830° C., the curves for the metallized and tantalum filaments cross and hence for higher temperatures the metallized filament has the better efficiency. When the

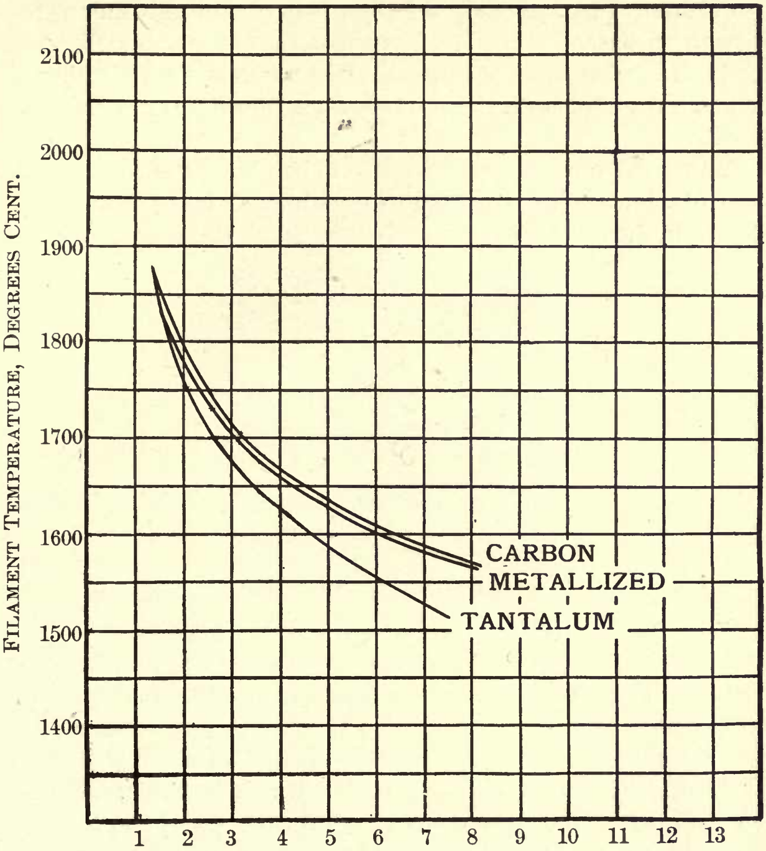


FIG. 27 WATTS PER CANDLE POWER

curves are produced to about 1875° C., the curve for the tantalum filament crosses that for the carbon so that beyond this point the latter would be more efficient if it could be operated at such temperatures. This too shows that it is due to the ability of the tantalum filament to withstand high temperatures without too rapid disintegration that it has so high an efficiency.

When we consider the curve for the metallized filament with respect to that of the carbon it is seen that it falls below that of the latter and tends to fall further below it at the higher temperatures; that is, as the temperature is increased, the metallized filament becomes relatively more and more efficient for any given temperature. Evidently then it is due not so much to its ability to withstand high temperatures that the metallized filament is the more efficient but rather to a selective radiation that becomes more and more pronounced as the temperature is increased.

Connected closely with the life of the lamps is the condition of the filaments after a period of burning. The carbon filament is shown in the micro-photographs*, Fig. 28, when new, after 1000

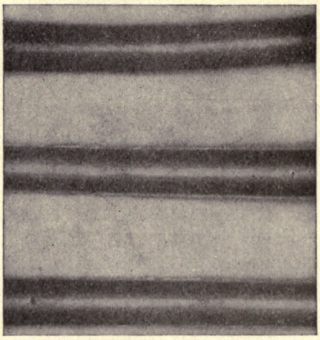


FIG. 28 CARBON FILAMENT

hours' burning under condition A and after 800 hours' burning under condition B. Little or no disintegration or breaking up of the filament is shown. It is almost as smooth and strong looking after 800 hours of the hard service as it was when it was new. Fig. 29 shows the micro-photographs of the metallized filaments when new, after 1000 hours under condition A and 800 hours under condition B. It is seen that after the different periods of

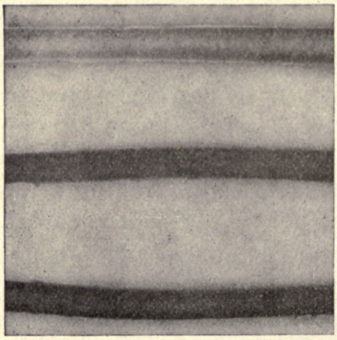


FIG. 29 METALLIZED FILAMENT

*Taken by Mr. David Klein, Department of Chemistry of University of Illinois.

burning, the filament is not quite as smooth as when new, but is pitted somewhat and has decreased in size a little. The most remarkable change, however, is shown in the case of the tantalum filament in Fig. 30. When new it is smooth and cylindrical, show-

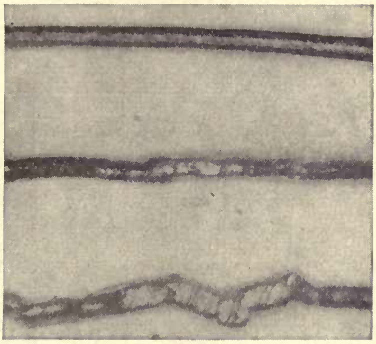


FIG. 30 TANTALUM FILAMENT

ing slight pittings or markings. After 1000 hours under condition A it has roughened up a great deal, being covered with notches and ridges due perhaps to unequal evaporation of the filament. The filament burned on alternating current shows a greater change even than that burned under condition A. It appears to have a sort of a segmented structure; in fact, in places along the filament it appears as if small sections had fallen out a part of the way and had been caught and welded again. When the filament is in this condition even a slight jar will serve to shatter the entire filament. One lamp after burning for almost 800 hours under condition B was dropped a short distance. After being lighted it was found that the filament had been broken and welded together again in no less than eight places.

A summary of the performance of the lamps on the life and efficiency tests is shown in Table 4, together with a table of the costs of energy and renewals at different rates per kilowatt-hour. This latter table is shown graphically in the curves of Fig. 31 and 32. These curves are plotted between "Total cost in cents per candle power hour for lamps and energy" as ordinates and "Cost of energy per kilowatt-hour" as abscissas. Fig. 31 shows the curves for lamps operating under condition A, that is, upon a very well regulated direct current circuit, while Fig. 32 is for

TABLE 4

SUMMARY OF LIFE AND EFFICIENCY TESTS

Operating Condition	Carbon		Metallized		Tantalum	
	A	B	A	B	A	B
Av. Mean Horizontal C. P.						
(a) (new)	24.9	25.2	20.6	20.5	19.8	19.8
(b) (400 hrs.)	19.7	16.4	18.1	16.1	19.9	16.5
(c) (800 hrs.)	16.5	12.3	14.9	14.2	17.2	14.8
Spherical Reduction Factor (a) (new)	.810		.803		.797	
(b) (400 hrs.)	.803		.805		.811	
(c) (800 hrs.)	.794		.801		.865	
Av. Spherical Candle Power (a) (new)	20.2	20.4	16.6	16.5	15.8	15.8
(b) (400 hrs.)	15.8	13.2	14.6	13.0	16.1	13.4
(c) (800 hrs.)	13.1	9.8	11.9	11.4	14.9	12.8
Av. Watts per Lamp	73.3	72.6	51.9	51.8	42.0	39.7
Av. Initial Watts per C. P.	3.00	3.1	2.62	2.62	2.02	1.99
Rated Watts per C. P.	3.1		2.5		2.0	
Total Lamp Hours	8180	7766	7963	4900	6779	6123
Total Candle Power Hours	165236	135905	144130	80905	137614	105928
Total Kilowatt Hours	599.6	563.8	413.3	253.8	284.7	243.1
No. Burnouts in 800 Hrs.	0	1	1	8	2	4
Cost of Lamps Each	$.17		$.25		$.51	
Total Cost Lamps & Renewals	$1.70	$1.87	$2.75	$4.08	$6.12	$6.83
COST OF POWER PER KW. HR. — Total Cost of Lamps and Energy Per C. P. Hr.						
$ .01	$ .00466	$ .00553	$ .00477	$ .00818	$ .00652	$ .0092
$ .03	$ .0119	$ .0138	$ .0105	$ .0144	$ .0107	$ .0133
$ .05	$ .0192	$ .0221	$ .0162	$ .0207	$ .0148	$ .0179
$ .07	$ .0264	$ .0305	$ .0220	$ .0270	$ .0189	$ .0225
$ .10	$ .0373	$ .0429	$ .0306	$ .0364	$ .0252	$ .0295
$ .12	$ .0447	$ .0512	$ .0363	$ .0427	$ .0293	$ .0343
$ .15	$ .0555	$ .0637	$ .0449	$ .0520	$ .0356	$ .0418
$ .20	$ .0736	$ .0843	$ .0593	$ .0678	$ .0459	$ .0524

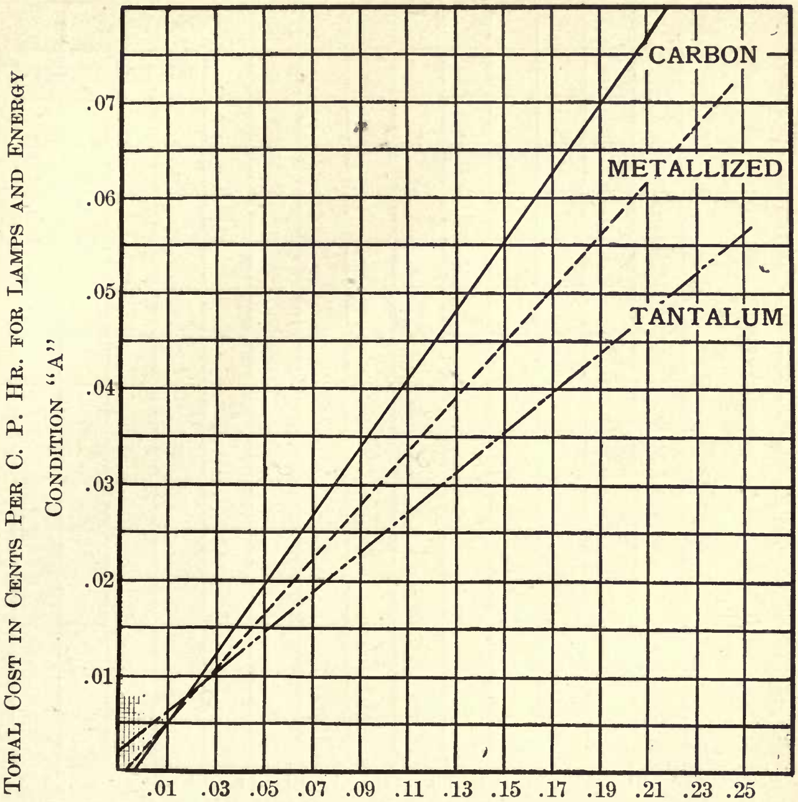


FIG. 31 COST OF ENERGY PER K. W. HOUR

lamps upon poorly regulated alternating current circuit with some vibration, that is, condition B.

Considering the curve for the carbon lamp working under condition A it is seen that for very low prices per kilowatt-hour for power, this lamp is the most economical on account of the small number of burn-outs and the low cost of the lamps. For costs of power from $.011 to $.022 per kilowatt-hour the metallized lamp gives the lowest cost, while for all the higher prices of energy the tantalum gives the best economy. For condition B the relative performance does not change a great deal, though on account of the large number of burn-outs with the metallized lamp at no time does it give the most economical results.

These results seem to show that so far as economy of oper-

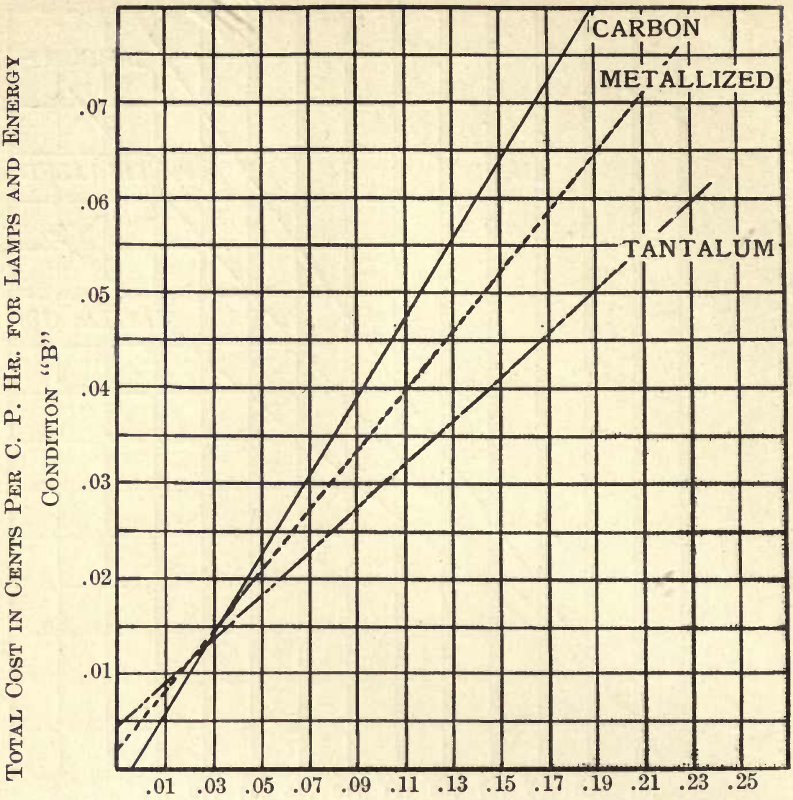


FIG. 32 COST OF ENERGY PER K. W. HOUR

ation goes, the metallized lamp has practically no field in incandescent lighting. From the standpoint of low cost of renewals, an important item with lighting companies that furnish free renewals, it cannot compete with the carbon or tantalum lamp, especially upon poorly regulated circuits and where there is vibration or rough usage. In cost of power consumption the carbon lamp leads for very low costs of power, and the tantalum for higher costs of energy. The metallized lamp seems to have a narrow field upon very well regulated circuits where the cost is between $.02 and $.03 per kilowatt-hour.

SUMMARY

As a summary it might be well to consider separately the three lamps and compare them with respect to the following eight considerations which determine the choice of an incandescent lamp.

1. Efficiency.
2. Cost of Operation.
3. Maintenance of Candle Power and Efficiency.
4. Life.
5. Quality of Light.
6. Distribution of Light.
7. Susceptibility to Voltage Variations.
8. Ability to Withstand Rough Usage.

1. Efficiency

In the matter of efficiency alone, this test as well as all other tests which have been made with these lamps shows conclusively that the metallized lamp is much superior to the carbon, and the tantalum is as much superior to the metallized. The difference between 3.1 watts per candle and 2.0 watts per candle, about 28 per cent, is sufficient to outweigh almost all other considerations. It means that a 20 candle power metallized or 22.5 candle power tantalum lamp can be operated with the same amount of energy as a 16 candle power carbon lamp. It means that a power plant which is running with a heavy overload of carbon lamps would, if the carbon lamps were exchanged for the same number of candle power of the newer lamps, be operating at about normal load with the consequent advantages. In the same way a method is provided to lighten overloaded feeders without any decrease in the candle power of light furnished.

2. Cost of operation

The curves of Fig. 31 and 32 show that upon well regulated circuits each type has a field of its own within which it is the most economical. For very low costs of power the carbon lamp gives the best economy. Hence particularly for persons who generate their own current it would not pay to change from carbon to the higher efficiency lamps, because in this case either the cost of power is low or else the fuel bill, the only item in which there would be a saving by using high efficiency lights, is not large compared with the other expenses such as attendance charges, taxes and interest. When the cost of energy is high, as it is in most cities, the tantalum lamp would be the best to use. The metallized lamp seems to be restricted to rather narrow limits of power cost and to good operating conditions. The newer types of lamps would have a great field in lighting railroad trains and steamships where the cost of power is always high, if filaments were robust enough to withstand the shocks and vibrations that are usually present. It seems that it might be possible and advisable for manufacturers to develop series tantalum lamps for this purpose. The filaments that would be used in a series lamp would no doubt be strong enough to withstand the vibrations and jars found in this service and their economy of current consumption would make them much preferable to the carbon lamp.

3. Maintenance of candle power and efficiency

In regard to maintaining candle power and efficiency the newer lamps make by far the best showing, the two being almost the same in this respect. The metallized and tantalum lamps have a drop of respectively 20 and 19 per cent in candle power in 1000 hours under condition A while the carbon drops 32 per cent in the same time and under the same conditions. The change in efficiency for the three lamps is in about the same proportion.

4. Life

Comparing the lamps upon the basis of average life to 80 per cent of the original candle power, which is standard for the carbon lamp, the following results are obtained.

TABLE 5

Condition	Life in hours		
	Carbon	Metallized	Tantalum
A	400	780	820
B	225	350	350

This method of comparison is if any thing unfair to the higher efficiency lamps, because, owing to their higher first cost, the smashing point should be after the lamps have reached a candle power considerably less than 80 per cent of the original. It serves, however, to show the superiority of the newer lamps in this respect.

5. Quality of light

The quality of the light from the metallized and tantalum lamps is much the same, both being considerably whiter, softer and more pleasing to the eyes than that of the carbon lamp. Being a whiter light, the newer lamps show more nearly the true values of colors than the carbon lamp and hence are superior for lighting dry goods and clothing stores, art and picture galleries and other places in which colors must be judged. The intrinsic brilliancy of the three kinds of filaments is approximately

Carbon	140 C. P. per sq. in.
Tantalum	165 C. P. per sq. in.
Metallized	190 C. P. per sq. in.

On account of the great intrinsic brightness of the newer types of filaments, particularly the metallized, it is not advisable to use these lamps for interior lighting when they are placed low enough to be in the line of vision, unless they are provided with ground glass or opal globes.

6. Distribution of light

The distribution of the carbon and metallized lamps is so nearly identical as to admit of little choice between them in this particular. The tantalum lamp differs from these in having a low tip candle power which is a point in its favor when used with reflectors.

For use with reflecting globes the most efficient lamp for any given watt per candle consumption would be one with a long straight filament mounted vertically. This kind of an arrangement gives the condition where the minimum proportion of light is radiated downward and upward, but gives a distribution which can be changed to suit the requirements by means of reflectors, and is such that the minimum light is lost in the base. Getting a downward distribution by placing the greater part of the filament horizontal, as has been done in many of the "downward light" lamps on the market, is an inefficient method. It is true that these lamps throw the maximum of their intensity further down from the horizontal than an ordinary lamp, but in so doing just as much light is thrown upward where it is mostly lost in the base and on the ceiling by absorption and improper reflection. To get light where it is needed and do it most efficiently is accomplished by mounting the filament so that as nearly as possible the entire length of it is parallel to the axis of the base, and then using good reflectors. The tantalum lamp meets this requirement very well, as is shown by its low tip candle power which indicates a small loss of light in the base. The intensity at angles even up to 30° from the tip is low in this lamp. The same condition would be shown at the base if the distribution were not changed by its presence. Near the base all light that has its course changed downward by reflectors must strike the reflector at a large angle. This, of course, is a condition that favors absorption and losses. With the tantalum the radiation in these unfavorable directions is less than in the other two and is superior for that reason if reflectors are used. When the lamps are used bare the carbon and metallized give a greater candle power downward where it is generally needed than does the tantalum lamp.

7. *Susceptibility to voltage variation*

Table 2 gives a comparison of the way these lamps act in regard to the very important point of susceptibility to voltage variation. For use upon poorly regulated feeders or at the end of long feeders that are sometimes heavily loaded, the metallized and tantalum lamps will make a much more uniform and pleasing light than the sensitive carbon lamp.

8. *Ability to withstand rough usage*

It is in this particular that the carbon lamp stands supreme. Long experience in making them has enabled the manufacturers to make a carbon filament that will withstand almost any reasonable usage. The filaments of both the metallized and the tantalum lamps are easily broken, especially after they have been burned for a while. The filament of the former is so fine that jars such as would be caused by screwing the lamp into or out of the socket sometimes make the two halves of the filament cross each other near the top. This short-circuits about one-third of the filament, and if the current is turned on, the lamp then burns at about three times the normal candle power. This, of course, greatly reduces the life of the lamps if the filaments are not separated. They may be shaken apart by tapping the lamp, but usually not before the filament has been materially weakened by burning at the high candle power. The filament of the metallized lamp is easily set to vibrating in an annoying manner. Often while working with them the vibration of the filaments was such that the flicker was easily seen on a piece of white paper at a distance of four or five feet from the lamp. It was only in some positions about the lamp that this was noticeable, but in these positions it was very pronounced and disagreeable. It seems to be caused principally by the reflections from the bulb of the lamp. The motion was in this way magnified. No such effect could be obtained from the carbon or tantalum lamps. The carbon filaments were stiff enough to resist the vibrations and the way in which the tantalum filaments were mounted prevented any vibration in them.

Conclusion

From the study of these lamps it appears that the carbon filament and the tantalum filament lamps can cover adequately all the phases of incandescent lighting that are now covered by the three types. For low power costs and for rough or unusual uses and for small candle power units the carbon lamp is best and often the only one that can be used. For higher costs of power upon poorly regulated circuits and for lightening the load upon overloaded stations the tantalum lamp is best. It is not recommended by its manufacturers for use upon alternating current, yet the results obtained show that although it does not do so well upon alternating current as it does upon direct current circuits, it still gives better economy for the higher power costs than the carbon lamp. The principal fault of the metallized lamp is that of mechanical weakness, which probably does not exist in the larger sizes where a heavier filament is used, so that for units of 40 or 60 candle power or above, this type of lamps is very satisfactory.

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